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Original article

# The relationship between steeplechase hurdle economy, mechanics, and performance

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## Abstract

**Background:** Research surrounding the steeplechase is scarce, with most research focusing primarily on how biomechanical factors relate to maintaining running speed while crossing barriers. One area that has not been well explored is the relationship between biomechanical factors and hurdling economy. The purpose of this study was to investigate how performance times and biomechanical variables relate to hurdling economy during the steeplechase.

**Methods:** This was accomplished by measuring running economy of collegiate and professional steeplechasers while running with and without hurdles. Biomechanical measures of approach velocity, takeoff distance, clearance height, and lead knee extension while hurdling, as well as steeplechase performance times were correlated to a ratio of running economy with and without hurdles.

**Results:** While oxygen uptake was 2.6% greater for the laps requiring five barriers, there was no correlation between steeplechase performance time and the ratio of running economy during the hurdle and non-hurdle laps. Results also indicated no correlation between the aforementioned biomechanical variables and ratio of running economy during the hurdle and non-hurdle laps.

**Conclusion:** Increasing approach velocity did not negatively affect running economy. Increased approach velocity is a benefit for maintenance of race pace, but does not hurt economy of movement.

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**Keywords:** Endurance; Racing; Running; Track and field

## 1. Introduction

In the quest to run faster, jump higher, and throw further, track and field events are continually being researched. One such event, the steeplechase, is filled with questions to be answered dealing with maintenance of horizontal velocity while negotiating obstacles and minimizing metabolic cost. Although it has been contested for over 150 years, it was not until 2005 that the women's steeplechase was introduced to the World Championships. In 2008 it was first contested in the Olympic Games. With the introduction of the women's steeplechase to world contests, interest in the race has increased<sup>1,2</sup> with organizations from junior national meets to major international championships including the event.

The steeplechase is 3000 m long with four barriers and one water pit per lap. The water pit is a barrier followed by a 3.66-m long water pit, typically about 0.7 m at the deepest point (Fig. 1). A steeplechaser encounters a total of 28 barriers and

seven water pit jumps during the race. The barrier heights are set at 0.914 m for men and 0.762 m for women (Fig. 2). There are no lane assignments, therefore steeplechasers often have to navigate the obstacles (barriers and water pit jump) surrounded by their competitors. With approximately 80 m between barriers there is no set stride pattern as seen in the hurdle races of shorter distances; therefore adjustments to running stride are made before each barrier. Just like running technique influences running economy,<sup>3</sup> hurdle and water jump technique should influence the economy of steeplechase running. As coaches and athletes begin to understand the techniques needed to improve hurdling economy during the steeplechase, athletes will achieve greater running speeds between and over obstacles.

To improve race performance, steeplechase runners must examine their distance running economy as well as their hurdling economy. Economy of distance running has been extensively researched,<sup>3–9</sup> and many biomechanical factors related to steeplechase hurdling have been examined,<sup>2,10–12</sup> however, economy of hurdling in the steeplechase has not been studied.

Better running economy leads to better distance running performance. In highly trained runners with similar ability and

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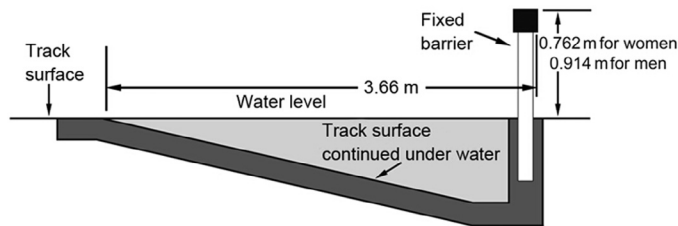


Fig. 1. Steeplechase water pit.

$\text{VO}_{2\text{max}}$ , running economy accounted for a significant amount of variation in 10,000 m race performances.<sup>5</sup> Running economy is measured by oxygen uptake at a given submaximal speed.<sup>13</sup> Trained runners are more economical at their specific race pace than at other paces.<sup>6</sup> Much time in the steeplechase is spent between barriers, therefore, good distance running economy will benefit the athlete.

In addition to high distance running economy, successful steeplechasers need an economical hurdling and water jump technique. There are two ways to clear the non-water pit barriers in a steeplechase race. The first is the hurdle technique in which the athlete keeps the lead leg knee slightly flexed and pulls the trail leg through after the lead leg clears the barrier. The second is the step-on technique where the athletes put one foot on top of the barrier, thus taking off and landing on the same foot. From a biomechanical viewpoint the hurdle technique is more effective for maintaining velocity.<sup>2,12</sup>

Faster overall speeds come from having a steady pace in distance running; therefore, one of the most important considerations in successful steeplechase hurdling is maintenance of horizontal velocity. Biomechanical measures that have previously been used to describe steeplechase hurdling include horizontal velocity into, over, and exiting the hurdle and water jump; takeoff distance; landing distance; crouch height; clearance height; push-off angle; hip, trunk and knee angles during flight; and takeoff and landing step lengths. An understanding of how these biomechanical characteristics relate to maintaining running speed while crossing the barriers already exist for men and women.<sup>1</sup> However, the relationship between these characteristics and the economy of steeplechase hurdling is unknown.

This study investigated the difference in oxygen uptake while running with five hurdles every 400 m and no hurdles every 400 m. We also measured approach velocity, clearance height, takeoff distance, and lead knee extension since they all contribute to the maintenance of horizontal velocity.<sup>1</sup> Measuring these biomechanical factors while also measuring running economy (oxygen uptake at a given submaximal speed) will allow a comparison of steeplechasers technique as it relates to running

economy. We expected that athletes with a smaller economy ratio would have a greater approach velocity, lower clearance height, greater takeoff distance, and greater lead knee extension.

## 2. Materials and methods

### 2.1. Participants

Ten female steeplechasers participated in this study (age:  $25 \pm 5$  years; height:  $1.70 \pm 0.05$  cm; mass:  $58.6 \pm 4.5$  kg; season best 3000 m steeplechase time:  $677 \pm 29$  s). Each participant was either a Division 1 NCAA or professional steeplechase athlete. Participants were contacted in person or by phone and asked to participate in the study. All procedures were approved by the appropriate institutional review board. Written informed consent was obtained from subjects prior to participation in the study.

### 2.2. Protocol

The participants' height, weight, age, personal best, and season best steeplechase time were recorded prior to beginning testing. All running took place at the Brigham Young University outdoor track. While wearing a portable metabolic system (K4 telemetry system; COSMED, Concord, CA, USA), participants completed their typical warm-up followed by one 800 m interval (two laps around the outdoor track). Only rest days or recovery runs were completed in the 3 days prior to testing. Participants then ran four 800 m intervals (from a standing start) with 3 min rest between intervals. Two of the intervals were over steeplechase barriers and two were without barriers. Intervals alternated between running with and without the barriers. Steeplechase barriers were set at 0.762 m (30 in). There were five barriers per 400 m lap spaced evenly around the track (providing a total of 10 barriers) in each hurdling interval. Only barriers without the water pit were chosen to isolate the effect of hurdling while running at steeplechase pace. Participants ran all intervals at their individual season best steeplechase race pace. Order of intervals was counter balanced as each subject served as his own control. Five subjects started with a non-hurdle interval and five started with a hurdle interval. Oxygen uptake was measured using the COSMED K4 telemetry system. It has been shown to be an accurate and reliable system of measuring oxygen uptake.<sup>14</sup> Since hurdling was included during the intervals, our measure of oxygen uptake is combined running/hurdling economy during the intervals with hurdling. Throughout the text, running economy will be defined as the economy of running with or without hurdling included depending upon the condition. Running economy was determined by the participants' oxygen uptake divided by their running speed in meters per second expressed as mL/kg/min. Running speed was confirmed with a stopwatch. All interval times were within 1.5% of the average interval time for each subject.

Two of the barriers were on the straight sections of the track. A video camera running at 120 Hz (Exilim FH-25; Casio, Tokyo, Japan) was placed to film the athlete's hurdling the barriers from a sagittal view at each of these barriers. A two-dimensional analysis was completed using Vicon Motus 9.2 (Vicon Corp., Colorado Springs, CO, USA). Measures of

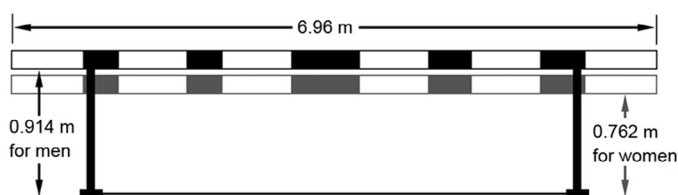


Fig. 2. Steeplechase barrier.

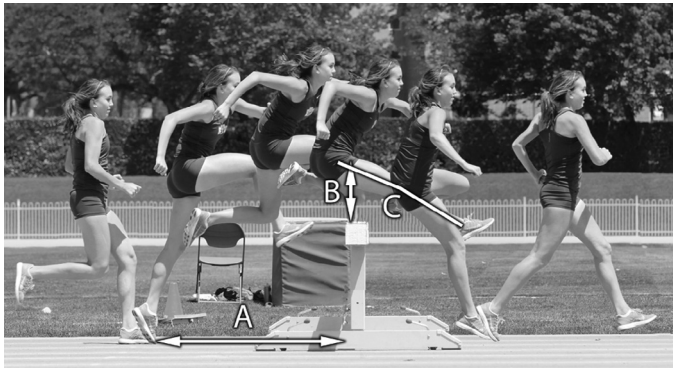


Fig. 3. Description of dependent variables. A: takeoff distance, B: clearance height, C: lead knee extension.

approach velocity (average velocity of the front of the torso, from 5 m before barrier to 2.5 m before barrier), clearance height (the vertical distance between the joint center of the lead leg hip and the top of the hurdle at the high point of the jump), takeoff distance (the horizontal distance from the takeoff toe and the front edge of the barrier), and lead knee extension (the greatest angle of extension of the lead knee until the lead foot is past the barrier) were calculated using Vicon Motus 9.2 (Fig. 3).

### 2.3. Statistical analysis

A linear regression was used to determine the correlation between the ratio of hurdle lap running economy to non-hurdle lap oxygen uptake to an athlete's season best 3000 m steeplechase time. Running economy was found by dividing the participants' oxygen uptake by their running speed for both the hurdle and non-hurdle intervals. We expected that athletes with a faster 3000 m steeplechase time would have a smaller ratio.

A stepwise multiple linear regression was used to determine the correlation between the ratio of hurdle lap running economy to non-hurdle lap running economy to approach velocity, clearance height, takeoff distance, and lead knee extension. The stepwise approach was taken as previous studies did not lead us to a clear expectation of which variables would most likely show significance. Smaller velocity ratios would show a smaller difference between hurdle and non-hurdle laps. Alpha was set at 0.05 for both analyses (SPSS, version 21; IBM Corp., Armonk, NY, USA).

### 3. Results

There was no correlation between steeplechase performance time and the ratio of hurdle lap running economy to non-hurdle lap running economy ( $F = 0.742$ ,  $p = 0.414$ ). Fig. 4 contains a scatterplot of these findings. Relative oxygen uptake accounting for body mass in the intervals with hurdles ( $51.9 \pm 4.0$  mL/min/kg) and the intervals without hurdles ( $50.6 \pm 4.9$  mL/min/kg) was significantly different ( $t = -2.761$ ,  $p = 0.011$ , Cohen's  $d = 0.159$ ). Average running speed was 4.41 m/s for the hurdle intervals and 4.43 m/s for the non-hurdle intervals. Also, no greatest difference from the average interval speed for any subject was 1.4%. Running/hurdling economy in the intervals with hurdles ( $0.1319 \pm 0.0241$  mL/m/kg) was significantly

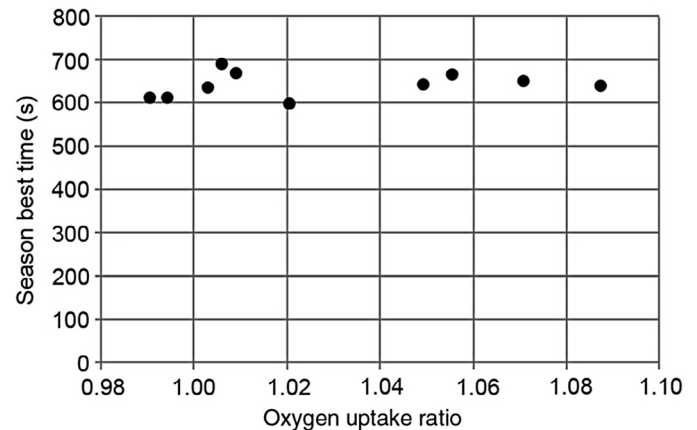


Fig. 4. Steeplechase performance time vs. oxygen uptake ratio ( $p = 0.414$ ). This ratio is the oxygen uptake while running with hurdles divided by the oxygen uptake while running without hurdles.

lower from running economy in the intervals without hurdles ( $0.1362 \pm 0.0252$  mL/m/kg;  $t = 2.941$ ,  $p = 0.016$ ).

No significant predictive model emerged in the stepwise linear regression model that related the measured hurdle biomechanics to the ratio of hurdle lap running economy to non-hurdle lap running economy. Means  $\pm$  SD for approach velocity, takeoff distance, clearance height, and lead knee extension were:  $4.26^\circ \pm 0.54^\circ$ ,  $1.22^\circ \pm 0.32^\circ$ ,  $0.36^\circ \pm 0.07^\circ$ , and  $139^\circ \pm 22^\circ$ , respectively.

### 4. Discussion

The purpose of this study was to determine how steeplechase performance time relates to a ratio of running economy during running with and without steeplechase barriers as well as which biomechanical factors (approach velocity, clearance height, takeoff distance, and lead knee extension) are most closely related to running economy during running with steeplechase barriers. The ratio of hurdle lap running economy to non-hurdle lap running economy was not related to the subjects' steeplechase time. Faster steeplechasers did not have a smaller ratio than slower steeplechasers. There are many factors that contribute to race times: temperature, wind, precipitation, elevation, experience, pacing abilities, and various physiological characteristics. More economical runners may not have run a race in ideal conditions; therefore they may have a slower season best time. In addition, some of the subjects may be more economical hurdlers but less economical at the water jump, while others may be opposite to that. We do not know how this affects race times but the water jump may have a greater effect on race time than hurdling does so a more efficient hurdler would not necessarily have a better personal best time. We suspect that the added variability due to these factors may have masked any correlations that do exist. Even though the running economy ratio was not connected to performance time, there may be other factors such as strength, power, or ability to change pace during a race that could be related to performance time.

A 3000 m steeplechase race on average takes 30 s longer than a flat 3000 m race.<sup>12</sup> This is about a 5% difference in time.



However, we found only a 2.6% difference in energy cost. One reason for the small difference could be that we only measured 800 m of hurdling at a time, whereas the steeplechase is 3000 m long race. Three thousand meters of continuous hurdling could lead to greater fatigue and therefore an increase in energy cost and race times. Another reason for the small difference could again be attributed to the fact that we only measured runners while hurdling and not during the water pit jump. We did this to isolate the effect that hurdle technique had on running economy, but the water jump may be a larger contributor to the increased energy cost and slower times that come with a steeplechase race.

There was no correlation between hurdle economy and technique for any of the variables measured (approach velocity, takeoff distance, clearance height, lead knee extension). The measurements of clearance height, takeoff distance, and lead knee extension were similar to those found in other studies.<sup>2</sup> Approach velocity was slower than the Olympic caliber athletes measured in other studies.<sup>2</sup> A limited number of subjects may have prevented us from finding a connection. With a high variability in hurdle technique, a greater number of subjects could potentially demonstrate which aspects of technique most affect hurdle economy. Not only is there inter-individual variability, but also intra-individual variability. Technique can vary depending on which lead leg is used and how well the subject judges their approach to the hurdle and the takeoff. More jumps with each leg as a lead leg could help to identify which aspects of technique most affect economy. As a race progresses, there may also be changes in technique that could affect hurdle economy as the runner fatigues. In addition, there is likely a non-linear correlation between hurdle economy and the measured biomechanical factors. We did not have a large enough range of data to determine such a connection. Future research should be conducted to elucidate these ideas.

Previous studies have found that increasing approach velocity helps to maintain horizontal velocity through the hurdle.<sup>1,2</sup> We found that increasing approach velocity did not affect hurdle economy. Therefore steeplechasers can accelerate into the hurdles to maintain horizontal velocity without causing a significant increase in energy expenditure. A steady pace in distance running leads to faster overall speeds<sup>15</sup> and maintaining horizontal velocity through the hurdle allows for a steadier pace.

We had a wide range of abilities in our subjects. Steeplechase times ranged from 625 to 720 s. Having such a large range of athletes increased our ability to find a correlation between hurdle mechanics and running economy. However, we were unable to find a correlation.

While the specific techniques of steeplechase hurdling were not connected to performance times, there are other training methods steeplechasers could consider to improve their performance. Plyometric training has been shown to improve running economy in distance runners likely through mechanisms residing in the muscles.<sup>16,17</sup> The addition of a plyometric training plan to a steeplechasers training may aid in preventing muscular fatigue which would allow the runner to have better running economy throughout the race. This may even help prevent potential changes in hurdle technique as a result of fatigue, allowing the runner to be more efficient over hurdles in the later

stages of the race. Future research could examine the relationship between plyometric training and improving hurdle economy and steeplechase performance times.

## 5. Conclusion

Running with five barriers per lap requires 2.6% greater oxygen consumption. However, steeplechase performance time was not related to the ratio of running economy with hurdles compared to running economy without hurdles. Running with hurdles does have a greater metabolic cost than running without hurdles. Hurdle technique was not correlated with economy; however future studies with greater subject numbers may be able to determine a connection. Accelerating into the hurdle allows the athlete to maintain horizontal velocity through the hurdle and athletes may continue to do so without sacrificing their economy. These suggestions may be affected by fatigue. When a runner is fatigued, there may be changes in technique. It is likely that optimal steeplechase hurdling technique changes as fatigue sets in.

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